DOCUMENT RESUME

ED 179 490 SP 011 303

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TITLE Movement Speed and Refractoriness.
PUB DATE 77
NOTE 18p.; Paper presented at Annual Conference of the North American Society for the Psychology of Sport and Physical Activity (Ithaca, New York, May 22-25, 1977)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Biomechanics; *Motion; Motor Reactions; *Physiology
IDENTIFIERS *Arm Swing

ABSTRACT

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ED179490

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Movement Speed and Refractoriness

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When a reaction to each of two closely spaced stimuli is required, it is usually found that the second reaction is delayed. This phenomenon which is generally known as the "Psychological Refractory Period" (PRP) effect is illustrated in Fig. 1. When the S_1-S_2 interval is very short, RT_2 is greater than for longer S_1-S_2 intervals (compare Fig. 1A and Fig. 1B). However, when the second signal (S_2) occurs after RT_1, RT_2 approximates normal values (Fig. 1C).

INSERT FIGURE 1 ABOUT HERE

While several theories have been advanced to explain the phenomenon (see Smith, 1967 for a review) perhaps the most productive has been Welford's single-channel theory (1959). According to Welford, the main reason for the extra delay in RT_2 is that the central mechanisms cannot process the information from the second signal until they have completed processing the information from the first signal (S_1). In the meantime, the S_2 information is temporarily stored. When the S_1 processing is

completed (as is evidenced by the occurrence of the first response R_1) the channel becomes free and is then able to accept the S_2 information.

The single-channel theory predicts therefore, that the increase in RT_2 is directly caused by the amount of overlap of the two responses. At this point, it should be noted that subsequent refinements to the theory have been made (e.g., Welford, 1967), however, for the purposes of the present paper these details need not be specifically addressed here. In general, the evidence indicates that the single-channel model has provided a useful first approximation to observed data (Bertelson, 1966).

However, it should be recognized that apart from the 91-cm ballistic arm swing used by Henry and Harrison (1961), much of the early evidence regarding the PRP phenomenon has been obtained by using small movement responses such as key presses. An important contribution of the Henry and Harrison study (1961) was its emphasis on the movement characteristics of refractoriness. They defined refractoriness in terms of the inability to reverse the direction of the primary arm swing rather than in terms of an increase in reaction latency.

Subsequent work by Williams (1971a, 1971b, 1973, 1974, 1975) has developed this approach in three ways. First, the study of reaction latency according to classical PRP methods was applied to the arm swing situation. Second, the arm movement was extended spatially to enable more frequent presentation of S_2 _during_ the movement. Third, the question of the effects of complexity of either the primary or secondary movements has been examined. While the evidence from these studies provide some

general support for the single-channel model it is clear that further modifications to the theory are required to explain the additional delays that are usually found with the large movement paradigm (Williams, 1974).

An additional feature of this approach is that it has indicated that two kinds of refractoriness exist (Williams, 1971a, 1971b). One focusses on the delay in RT_2 ("temporal" refractoriness) and decreases as the interstimulus interval (ISI) increases while the other emphasizes the inability to modify the first movement ("movement" refractoriness) and behaves differently in that it increases along with ISI. To date however, the underlying relationship between these two types of refractoriness has remained unclear.

One likely reason for this state of affairs could be that movement refractoriness has been measured in terms of the inability to modify the primary arm swing before it passed through a certain point in space, whereas temporal refractoriness has been measured in terms of time, *per se* (Williams, 1971b). The present paper proposes to examine movement refractoriness according to the time dimension so that it can be more directly related to the temporal refractoriness effects of RT_2.

In addition, it is proposed to manipulate the speed of the primary movement in order to examine the effects on both kinds of refractoriness. In contrast to the previous studies which used maximal speed arm swings, it is expected that slower speeds would allow greater use of sensory feedback for control of the primary arm swing and as a consequence the central mechanisms would be less able to process any information about a

second response. It is hypothesized therefore that relatively slow speeds of the first movement will cause greater temporal refractoriness than maximal speeds.

Method

<u>Subjects</u> Twenty-two right-handed college males from the University of Otago, New Zealand were the subjects. All were volunteers.

<u>Apparatus</u> <u>and</u> <u>Movement</u> The apparatus was the same as that used recently (Williams, 1974) except that there was only one target string which was placed 180 cm from the starting reaction key. The string was held at one end by a microswitch and was fixed at the other end so that when the hand swung through, the microswitch was activated. The effective width of the target was 34 cm. The warning (W) first stimulus (S_1) and second stimulus (S_2) lights were placed in a fixed position slightly behind and above the target string.

As was the case in previous studies, the primary movement was an extended right-arm swing in the sagittal plane. In the starting position, the subject bent slightly forward at the waist, with his right hand held against the starting reaction key and with his left foot advanced. After a variable warning delay, the S_1 light flashed on and in reaction to it, the subject was required to swing his arm forward through the target string (which was approximately waist-high) to a final position with the hand directly above the head. The right arm was held straight throughout.

A leather guard, such as that used by archers, was strapped to the subject's wrist and forearm. Attached to it in a fixed position was a decelerometer which triggered a second microswitch when deceleration forces exceeded 1 g. At predetermined intervals after S_1, the S_2 light flashed on and in response to it, the subject was required to reverse the direction of the primary swing. This action triggered the decelerometer.

Three standard msec timers were used to record RT_1 (the time between S_1 and the subject's hand leaving the starting key), RT_2 (the time between S_2 and the initiation of the reversal response) and movement time (MT) which was the time between beginning the forward movement and striking the target string. A fourth timer measured deceleration time (DT) which was the time between the beginning of the forward arm swing and the initiation of reversal.[2]

Procedures Testing was carried out on 3 separate days with each session lasting about an hour. On the first day, practice of the primary arm swing with emphasis on reaction time, maximal speed and a full follow-through, was followed by introduction of the reversal movement. The subject was informed that in approximately half the trials S_2 would flash on and if it did, he was to reverse the direction of the swing immediately. The trials when S_2 did not occur were catch trials. Following practice, 46 experimental trials under maximal speed conditions were administered.

On the second day, the subject began with 10 - 15 practice trials under the maximal speed condition. He was then instructed to perform the primary swing under one of two slower speeds (66% of maximal or 33% of maximal). Each subject's criterion speed was determined by using the

mean movement time (MT) of the first day's catch trials and limits of $\pm$ 35 msec were set for these submaximal conditions. After the subject had achieved consistency in producing appropriate MTs, a further 46 experimental trials under the respective submaximal speed condition were given. The third session was the same as the second except that the submaximal speed condition was changed.

The order of the submaximal speed conditions was balanced out across subjects. The warning periods were 2, 3 or 4 sec. and were presented in random order. The experimental trials consisted of 25 reversal trials and 21 catch trials. These were presented randomly under the constraint that 5 reversal trials were given under each of the 5 ISI conditions (100, 200, 300, 400 and 500 msec).

Results

ANOVAs for MT revealed no significant differences within each speed condition across the ISI and catch conditions. As would be expected, the differences among speed conditions were considerable with the grand means being 361, 458 and 559 msec for the maximal, 2/3 and 1/3 speeds respectively.

Fig. 2 shows the two reaction time measures plotted as a function of ISI. RT_1 remained stable across all delay intervals and the only significant difference among speed conditions revealed by Tukey tests was under the shortest ISI where the 1/3 condition was 29 msec faster than the maximal condition.

INSERT FIGURE 2 ABOUT HERE

While RT_2 demonstrated typically elevated values the differences among speed conditions were significant [F (2,42) = 12.94, $p < .05$] as was that for ISIs [F (4,84) = 121.24, $p < .05$]. Moreover, the difference in trends between the submaximal and maximal speed conditions was confirmed by the significant ISI X Speed interaction [F (8,168) - 9.47, $p < .05$]. These results support the hypothesis that the slower movements would allow more use of sensory feedback information and thereby cause greater temporal refractoriness.

Deceleration times (corrected for the cases where ISI > RT_1) are plotted against ISI in Fig. 3. Tukey tests revealed significant differences between the submaximal and the maximal speeds for the 200, 300 , 400 and 500 msec ISIs; while the other comparison was not significant. It appears that reversal of the primary movement was more difficult under the slower speeds.

INSERT FIGURE 3 ABOUT HERE

Discussion

The RT_2 data for the fastest speed condition are typical of the findings with large response movements in that the trend decreases linearly as the S_1-S_2 interval increases. Moreover, as in previous work (Williams, 1973, 1974), the data do not fit the single-channel model very closely since the observed values of RT_2 for all except the longest ISI, exceed those predicted by the model (this may be confirmed by plotting RT_2 as a function of ISI - RT_1).

The shallower trend of RT_2 for the submaximal speeds is in agreement with the hypothesis that feedback information from the primary response would engage the central mechanisms and thereby cause further delay in the processing of S_2. It is interesting to note that the shallowness of the trends indicates that as the delay interval between S_1 and S_2 lengthens, it becomes proportionately more difficult to initiate the second response in the sense that there is not a 1:1 relationship between the S_1 - S_2 delay and the effect of feedback. If there were such a direct proportion, the trends would decrease linearly with a slope closer to minus 1.0. Thus, although temporal refractoriness as evidenced by RT_2 decreases as ISI lengthens, the data cannot be explained adequately by time delays caused by overlapping demands on the central processor. There appears to be an additional source of delay which increases with time.

Deceleration time provides evidence for movement refractoriness since it represents the time required to initiate reversal once the movement had begun. It is clear that the maximal speed movement achieved the fastest reversals. While the relatively level pattern for this condition contrasts to the increasing trends reported earlier (e.g., Williams, 1971b) it should be noted that the previous studies did not correct for the cases when S_2 occurred after RT_1

The submaximal speeds of movement became increasingly more refractory to reversal as the delay intervals increased; this was with the exception of the longest interval, by which time it is likely that the arm was decelerating anyway.

It might appear therefore, that the dilemma of two kinds of refractoriness remains. On the one hand we have RT_2 which represents the overall refractoriness according to the time taken to respond to S_2, while on the other hand, we have evidence for refractoriness to the amendment of a movement. It is suggested here however, that the present response situation consists of both central and peripheral components of refractoriness. The central component may be regarded as being synonymous with the single-channel concept of non-overlapping processing times while the peripheral component refers to the motor characteristics of the requirement for amendment. The use of RT_2 to represent refractoriness in fact combines both components and can obscure the characteristics of movement refractoriness.

The typical finding (including those presented here) that the single-channel model provides a first approximation to refractoriness has led to the necessity of identifying the sources of extra delay that might explain the observed data more fully (Williams, 1974). The present investigation suggests that in the large movement response situation at least, this source of extra delay is closely related to the movement refractoriness caused by the peripheral requirements. It seems obvious that for those who are interested in motor control processes, the concept of movement refractoriness could be usefulin examining the characteristics of large movement situations.

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FOOTNOTES

[1] At present on Sabbatical leave at the Department of Kinesiology, University of Waterloo.

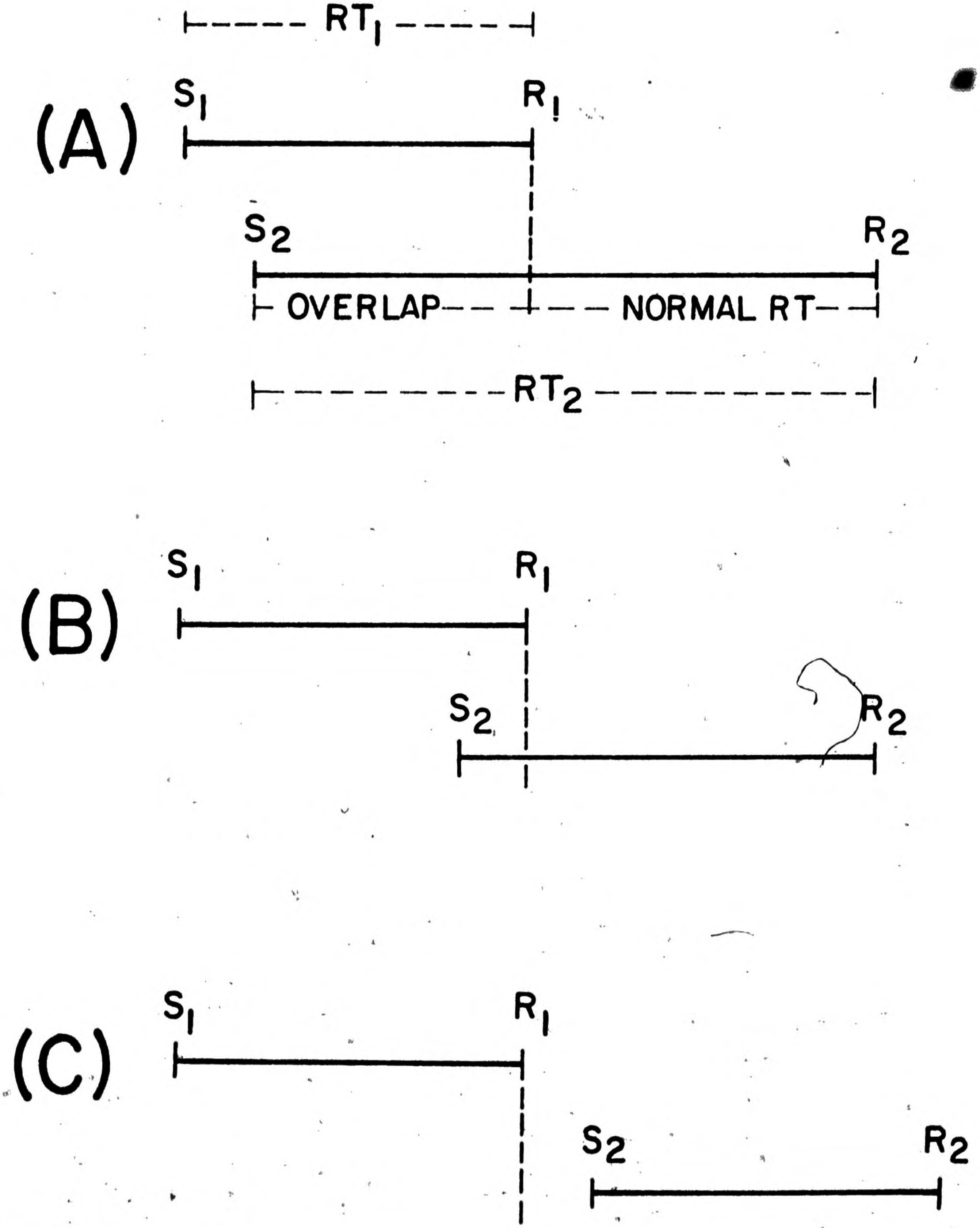
[2] While deceleration time may also be calculated as $DT = RT_2 + ISI - RT_1$, it should be noted that when $ISI > RT_1$ then DT requires subtraction of the time between RT_1 and the occurrence of S_2 in order to provide a more accurate measure of the reversal time.

FIGURE CAPTIONS

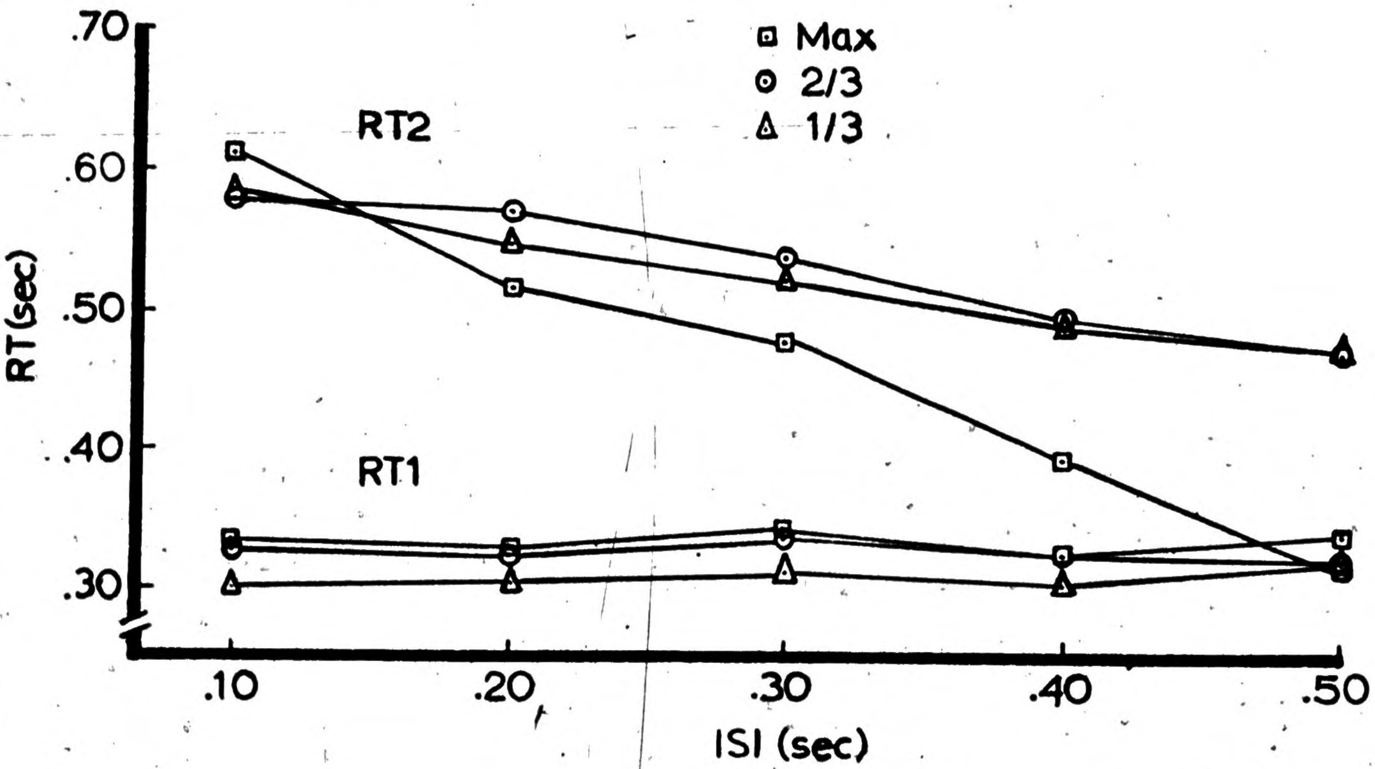
Fig. 1. Three of the possible sequences in a typical PRP study: (A) a very short $S_1 - S_2$ interval; (B) a long $S_1 - S_2$ interval with S_2 still arriving before R_1; and (C) a longer $S_1 - S_2$ interval where S_2 arrives after R_1.

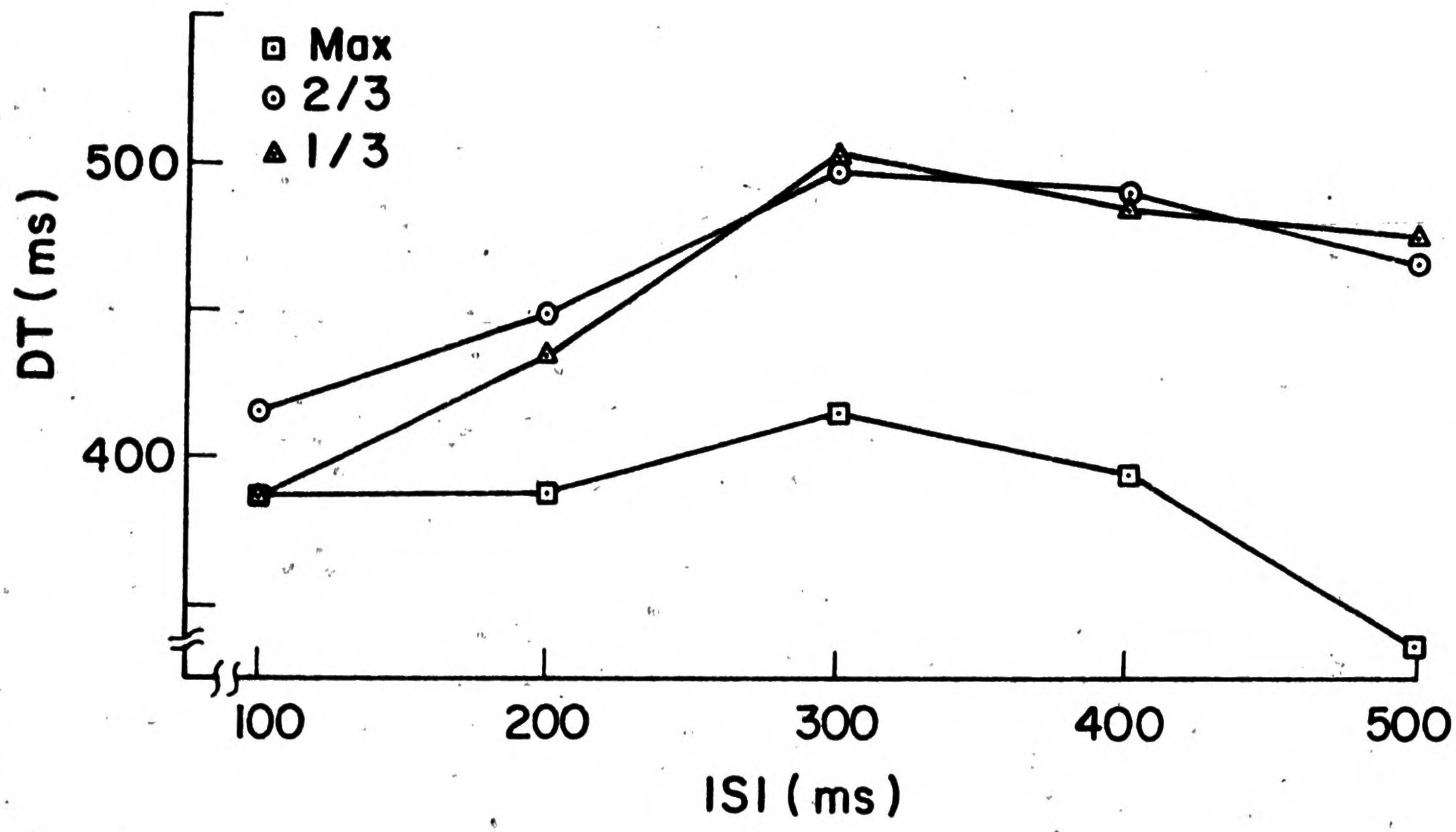
Fig. 2. Mean RT_1 and RT_2 for all speed conditions as a function of ISI.

Fig. 3. Mean Deceleration Times (corrected for ISI $>$ RT_1) as a function of ISI for all speed conditions.



RT$_1$
(A)
S$_1$
R$_1$
S$_2$
R$_2$
OVERLAP
NORMAL RT
RT$_2$
(B)
S$_1$
R$_1$
S$_2$
R$_2$
(C)
S$_1$
R$_1$
S$_2$
R$_2$


.70
.60
.50
.40
.30
RT(sec)
Max
2/3
1/3
RT2
RT1
.10
.20
.30
.40
.50
ISI (sec)



Max
2/3
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500
400
DT (ms)
100
200
300
400
500
ISI (ms)